ABRASION-RESISTANT STEEL

CROSS REFERENCE TO RELATED APPLICATION

[0001] This application is a divisional of co-pending U.S. Patent Application Serial No. 09/471,957 filed December 23, 1999.

BACKGROUND OF THE INVENTION

1. Field of the Invention

[0002] The present invention relates to a steel which exhibits excellent abrasion resistance and corrosion resistance in a state exposed to excessive abrasion and a weaving machine member, e.g., a flat steel heald, a dropper, a reed dent or a tunnel reed, which is likely abraded in contact with fibers.

2. Description of the Related Art

[0003] High-strength steels such as cutlery steel or tool steel have been used so far for such uses requiring abrasion resistance, e.g., a weaving machine member subjected to abrasion in contact with threads, and an electric or electronic member subjected to abrasion in contact with other members. Corrosion resistance is also one of the requirements for such steels, accounting for use environments.

[0004] Although durability of cutters, tools, weaving machine members, electric members or electronic members is greatly affected in response to use environment, the abrasion resistance of steel materials is the biggest influence on durability. In this regard, a carbon steel having a metallurgical structure hardened by quenching or cold-working has been used as a member where abrasion resistance is required.

[0005] For instance, a structure-hardened steel prepared by quenching a stainless steel SUS420J2 has been used so far as weaving machine members such as a flat steel heald, a

dropper, a reed dent and a tunnel reed. Such weaving machine members are subjected to an increasingly more severe abrading environment in response to material improvement of fibers used for fabrics and the high-speed process to enhance productivity. As a result, the lifetime of the members becomes shorter and shorter, and the members are necessarily replaced with new members on a frequent basis.

[0006] Since abrasion is the phenomenon which occurs under very complicated mechanisms, causes of abrasion at abraded parts have not been clarified yet, but high strength steels have been used based on an estimation of their abrasion resistance. In short, durability of a steel member has been evaluated in the state that the steel member is actually incorporated in an existing machine. As a result, it needs a fairly long time to judge the proper kind of steel required, which makes proper selection of the kind of steel difficult.

[0007] Abrasion resistance of a steel can be improved by structure-hardening or work-hardening. However, abrasive environments are getting more severe in response to enhancement of productivity which needs high-speed processing or the use of tough materials to be processed. Such severely abrading environments decrease durability of steel members, resulting in frequent replacement of steel members and the occurrence of damage derived from abrasion. The damages derived from abrasion are varied in response to abrading conditions, and hardness is not always proportional to the durability of steel members. In this sense, it is important to sufficiently recognize abrading mechanisms in use environments for development of kinds of steel suitable for such environments.

SUMMARY OF THE INVENTION

[0008] The present invention fulfills these requirements by providing a new steel which sufficiently endures excessive abrasion by dispersion of hard carbide precipitates in a steel matrix and, more significantly, provides a weaving machine member, which can be used

for a long time, made of a steel which is excellent in abrasion resistance even under severe abrading conditions.

[0009] The newly proposed steel consists essentially of 8.0-35.0 wt.% Cr, 0.05-1.20 wt.% C, 0.05-3.0 wt.% at least one of Ti, Nb, Zr, V and W, and has the structure that an amount of Ti, Nb, Zr, V and/or W carbide precipitates distributed in a steel matrix is adjusted to 0.1 wt.% or more in total.

[0010] The weaving machine member according to the present invention is made of a steel consisting essentially of 8.0-35.0 wt.% Cr, 0.05-1.0 wt.% C, up to 1.0 wt.% Si, up to 1.0 wt.% Mn, one or two of 0.05-1.0 wt.% Ti and 0.05-1.50 wt.% Nb with the proviso of 0.05-2.0 wt.% in total and the balance being Fe except inevitable impurities, and having the structure that a total amount of Ti and/or Nb carbide precipitates distributed in a steel matrix is adjusted to 0.1 wt.% or more.

BRIEF DESCRIPTION OF THE DRAWINGS

[0011] Fig. 1 is a graph illustrating the relationship between hardness and an abrasion coefficient;

[0012] Fig. 2 is a graph illustrating an effect of a total amount of carbide precipitates on an abrasion coefficient; and

[0013] Fig. 3 is a graph illustrating an effect of a total amount of Ti and Nb carbide precipitates on abrasion resistance.

DETAILED DESCRIPTION OF THE INVENTION

[0014] The inventors collected many samples damaged by abrasion as well as test pieces which were subjected to an abrasion test, and have studied the damaged parts from a microscopic viewpoint. Among most of the samples and test pieces, injuries just like grinding scratches were observed at abraded parts. As for samples collected from weaving machine members, injuries just like linear grinding scratches were observed at abraded parts.

Adhesion of hard particles such as alumina and silicon carbide was detected near the abraded parts and on surfaces of other members or threads facing the abraded parts. Such injuries and adhesion of hard particles prove that abrasions occur in co-existence of hard particles. Such abrasion is so-called "abrasive abrasion", wherein a steel member held in contact with another member or threads is scrubbed and ground during vibrating or sliding motion by hard particles present at the contact planes.

[0015] The abrasive abrasion is the most severe abrasion among various abrasion phenomena. A material resistant to such abrasive abrasion is urgently needed.

[0016] In order to improve abrasion resistance, the inventors examined a method of quench-hardening a high-carbon steel at first. A weight loss caused by abrasive abrasion was slightly reduced as hardness increased after quenching, but the quench-hardening did not realize remarkable improvement of abrasive resistance. That is, the abrasive resistance cannot be sufficiently improved by the addition of carbon to harden a steel structure. Improvement of abrasion resistance was not realized in a case of a steel hardened by cold working.

[0017] The inventors supposed the reason why endurance of steel materials against abrasive abrasion is not improved by structure-hardening or work-hardening as follows: Hard particles such as alumina and silicon carbide are much harder than a structure-hardened or work-hardened steel member. Since the structure-hardened or work-hardened steel member is not hard enough in comparison with hard particles such as alumina and silicon carbide, the structure-hardening or work-hardening is insufficient for suppression of abrasive abrasion.

[0018] During repetition of experiments for researching abrasion mechanism and a material which sufficiently endures such abrasive abrasion, the inventors discovered that resistance of a steel material to abrasive abrasion is remarkably improved by distribution of

hard carbide precipitates in a steel matrix. Concretely, the inventors researched quantitative effects of Ti, Nb, Zr, V and/or W carbide precipitates on endurance to abrasive abrasion from the viewpoint that Ti, Nb, Zr, V and/or W carbides have hardness nearly equal to hard particles such as alumina and silicon carbide. When a sufficient amount of Ti, Nb, Zr, V and/or W carbide precipitates are distributed in the steel matrix, the abrasive abrasion is suppressed, as shown in Fig. 1, compared with steel members having the same hardness but free from such carbide precipitates.

[0019] The newly proposed steel contains 8.0-35.0 wt.% Cr. If Cr content is less than 8.0 wt.%, the effect of Cr on corrosion resistance is poor. If Cr content exceeds 35.0 wt.%, hot workability of the steel is deteriorated, resulting in increased manufacturing cost.

[0020] The steel contains 0.05 wt.% or more of C to precipitate carbides in a total amount of 0.1 wt.% or more. The additive C is not only consumed in the generation of carbides, but also effectively strengthens a steel structure. However, an excessive addition of C above 1.20 wt.% promotes quantitative precipitation of huge eutectic Cr carbide which puts harmful influences on quality and hot workability of the steel.

[0021] At least one of Ti, Nb, Zr, V and W is added in an amount of 0.05-3.0 wt.%, so that an amount of Ti, Nb, Zr, V and/or W carbide precipitates in a steel matrix is kept at 0.1 wt.% or more in total. The lower limit 0.1 wt.% of Ti, Nb, Zr, V and/or W carbide precipitates is a critical value which has been discovered by the inventors during research of the effects of carbide precipitates on abrasion resistance. When the total amount of carbide precipitates is kept at 0.1 wt.% or more, the steel exhibits remarkably excellent abrasion resistance compared with a steel free from carbide precipitates. Precipitation of Ti, Nb, Zr, V and/or W carbides at 0.1 wt.% or more in a total amount is attained by the addition of Ti, Nb, Zr, V and/or W at a ratio of 0.05 wt.%. However, addition of Ti, Nb, Zr, V and/or W in an excessive amount more than 3.0 wt.% causes poor fluidity of a molten steel during a steel-

making process, generation of intermetallic compounds which are a detrimental influence on toughness, and also increase the cost of the steel.

[0022] The steel may contain other elements such as Ni, Mo and Cu. For instance, 0.2-5.0 wt.% Ni is effective for toughness and quench-hardening, 0.1-3.0 wt.% Mo is effective for toughness and corrosion resistance, and/or 0.2-3.0 wt.% Cu is effective for corrosion resistance and stress corrosion cracking resistance. As for other components which are incorporated in the steel, C content is preferably adjusted to 0.05-=1.50 wt.%, Si content is preferably adjusted to 0.02-2.5 wt.%, and Mn content is preferably adjusted to 0.02-3.0 wt.%.

[0023] In a case of a steel for use as a weaving machine member, one or two of 0.05-1.0 wt.% Ti and/or 0.05-1.50 wt.% Nb with the proviso of 0.05-2.0 wt.% are added, so as to keep a total amount of Ti and/or Nb carbide precipitates distributed in a steel matrix at 0.1 wt.% or more. Precipitation of Ti and/or Nb carbides at 0.1 wt.% or more in a total amount is attained by the addition of Ti and/or Nb at a ratio of 0.05 wt.%. However, excessive addition of Ti above 1.0 wt.%, Nb above 1.50 wt.% or Ti and Nb above 2.0 wt.% causes poor fluidity of a molten steel during the steel-making process and generates intermetallic compounds which are a detrimental influence on toughness.

[0024] The steel for use as a weaving machine member may further contain up to 1.0 wt.% Si and up to 1.0 wt.% Mn. Si is added as a deoxidizing agent during a smelting process, but an excessive amount of Si above 1.0 wt.% causes poor toughness. Mn is also added as another deoxidizing agent during a smelting process, but an excessive amount of Mn above 1.0 wt.% increases the ratio of residual austenitic grains during quenching, resulting in deterioration of hardness and toughness.

EXAMPLE 1

[0025] Various steels having the compositions shown in Table 1 were prepared in a conventional smelting process and cast to slabs. Each slab was subjected to solution treatment and hot rolled to a thickness of 5 mm. A hot rolled steel strip was heat treated 9 hours at 870°C and then cooled in an oven.

[0026] TABLE 1: STEELS USED IN EXAMPLES

Example No.	Alloying components and contents (wt.%)										Note
	C	Si	Mn	Ni	Cr	Ti	Nb	Zr	V	W	
1	0.21	0.59	0.59	0.17	9.57	0.10	0.04	0.05	---	---	PRESENT INVENTION
2	0.30	0.62	0.64	0.15	11.58	0.19	0.02	---	0.06	0.08	
3	0.39	0.51	0.61	0.04	12.82	0.40	---	---	---	---	
4	0.22	0.53	0.57	0.03	13.04	---	0.41	---	---	---	
5	0.61	0.54	0.58	0.04	13.13	0.26	0.18	---	---	---	
6	0.29	0.58	0.61	0.21	13.43	0.31	0.25	0.15	0.12	---	
7	0.68	0.57	0.65	0.19	13.48	1.12	---	---	---	---	
8	0.34	0.51	0.62	0.17	18.52	0.13	0.17	---	---	0.23	
9	0.91	0.56	0.61	0.12	23.51	0.16	1.15	0.08	---	0.11	
10	1.22	0.52	0.59	0.16	31.48	---	2.98	---	---	---	
11	0.24	0.58	0.59	0.15	1.35	---	---	---	---	---	COMPARATIVE EXAMPLES
12	0.21	0.52	0.61	0.04	5.32	---	---	---	---	---	
13	0.32	0.55	0.62	0.21	6.59	---	---	---	---	---	
14	0.41	0.48	0.59	0.03	10.11	---	---	---	---	---	
15	0.59	0.54	0.58	0.03	11.93	---	---	---	---	---	
16	0.68	0.54	0.64	0.17	13.48	0.03	0.03	---	0.01	---	
17	1.26	0.59	0.61	0.15	13.52	0.04	0.04	0.01	---	0.02	

[0027] Test pieces for an abrasion test were cut off each annealed hot-rolled steel strip, heated 15 minutes at 1100°C and then cooled to room temperature. Carbide precipitates distributed in each test piece were quantitatively measured, and endurance of each test piece against abrasive abrasion as well as its corrosion resistance were examined as follows.

Measurement Of An Amount Of Carbide Precipitates

[0028] A test piece containing carbide precipitates at a ratio controlled by solution treatment and precipitation treatment was dipped in an alcoholic iodide solution and dissolved therein by ultrasonic irradiation. The amount of carbides remaining in the solution was measured. States of carbides were identified by X-ray diffraction, and amounts of individual metallic elements were measured by wet analysis and gas analysis.

Evaluation Of Weight Loss By Abrasive Abrasion Resistance

[0029] Endurance against abrasive abrasion was tested using a pin-on-disc type frictional wear testing machine. A columnar test piece having a contact surface of 5 mm in diameter was fixed to a while, while an abrasive paper to which silicon carbide particles were applied was stuck to a disk. The test piece at the pin was charged with a load F(=4000gf) and scrubbed with the rotating disc at a friction speed of 0.7m/seconds along a distance L (=0.5km). Thereafter, a weight loss W (mm^3) of the test piece was measured. An abrasion coefficient C was calculated from the measured value according to the formula of $C=W(L\times F)$ for evaluation of abrasion resistance.

Evaluation Of Corrosion Resistance

[0030] Corrosion resistance of the test piece was evaluated from generation of rust on a surface of the test piece, after the test piece was subjected for 72 hours to a 5% saltwater spray test.

[0031] Test results are shown in Table 2.

[0032] Rust was generated on a surface of any test piece of Comparative Examples 11 to 13 whose Cr content was less than 8 wt.%, but generate of rust was not observed on a surface of any test piece of Examples 1 to 10 and also Comparative Examples 14 to 17. It is recognized from these results that Cr content of 8 wt.% or more is necessary to ensure corrosion resistance.

[0033] An abrasion coefficient C was a big value above 18 $mm^2/kgf \times 10^{-8}$, as for any test piece of Comparative Examples 11 to 15 free from distribution of carbide precipitates. Since the abrasion coefficient C had a tendency to become smaller as carbide precipitates increased, the inventors graphically illustrated the total amount of carbide precipitates in relation with the abrasion coefficient C and confirmed the presence of the relationship as shown in Fig. 2. That is, the abrasion coefficient C decreased as the total amount of carbide precipitates increased, and surprisingly decreased when the total amount of carbide precipitates was 0.05 wt.% or more. The abrasion coefficient C was decreased to a value below 1000 $m^2/kgf \times 10^{-8}$ by adjusting the total amount of carbide precipitates to 0.1 wt.% or more. Such lower value is less than half of the abrasion coefficient of a test piece free from carbide precipitates and is evidence that the newly proposed steel is excellent in abrasion resistance.

[0034] TABLE 2: EFFECTS OF TOTAL AMOUNTS OF CARBIDE PRECIPITATES ON ABRASION COEFFICIENTS

PRESENT INVENTION				COMPARATIVE EXAMPLES			
Example No.	a total amount of carbide precipitates wt.%	an abrasion coefficient $mm^2/kgf \times 10^{-8}$	corrosion resistance	Example No.	a total amount of carbide precipitates wt.%	an abrasion coefficient $mm^2/kgf \times 10^{-8}$	Corrosion resistance
1	0.21	250	no rusts	11	0	2006	generation of rusts
2	0.38	139		12	0	2112	
3	0.46	116		13	0	1998	
4	0.43	124		14	0	1985	no rusts
5	0.50	107		15	0	1805	
6	0.91	59		16	0.05	1650	
7	1.28	42		17	0.09	1125	
8	0.52	103		A total amount of carbide precipitate is a summary of Ti, Nb, Zr, V and W carbide precipitates. An abrasion coefficient of $1000mm^2/kgf \times 10^{-8}$ is regarded as an acceptable value.			
9	1.63	30					
10	3.26	15					

EXAMPLE 2

[0035] Various steels having compositions shown in Table 3 were prepared in a conventional smelting process and cast to slabs. Each slab was subjected to solution treatment and hot rolled to a thickness of 5 mm. A hot rolled steel strip was heat treated 9 hours at 870°C and then cooled in an oven. The annealed steel strip was pickled with an acid[,] and then formed to a cold rolled steel strip of 0.30 mm in thickness by repetition of cold rolling and annealing.

[0036] TABLE 3: STEELS USED IN EXAMPLES

Example No.	Alloying components and contents (wt.%)							Note
	C	Si	Mn	Ni	Cr	Ti	Nb	
1	0.23	0.55	0.57	0.16	9.92	0.12	0.11	Present Invention
2	0.31	0.59	0.61	0.14	10.53	0.22	0.12	
3	0.33	0.61	0.59	0.19	13.26	0.59	0.41	
4	0.65	0.53	0.59	0.19	13.12	1.25	0	
5	0.32	0.56	0.63	0.17	13.52	0	1.06	
6	0.88	0.51	0.59	0.14	13.56	0.71	0.76	
7	1.21	0.54	0.62	0.16	18.48	1.63	0.59	
8	0.32	0.51	0.59	0.17	4.31	0.008	----	Comparative Examples
9	0.62	0.49	0.58	0.15	13.37	0.04	0.02	
10	1.19	0.52	0.64	0.19	13.49	0.04	0.04	
11	0.33	0.44	0.56	0.11	13.41	----	----	SUS420J2

[0037] Test pieces for an abrasion test were cut off each cold rolled steel strip and formed to a flat steel heald as a weaving machine member. Each test piece was held 1 minute at 1050°C in a non-oxidizing atmosphere and then cooled to a room temperature.

[0038] An amount of carbide precipitates in each test piece was measured, and corrosion resistance of the test piece was tested in the same way as in Example 1. Abrasion resistance was evaluated as follows.

[0039] In the abrasion test, a synthetic fiber thread (TFD75/36F, 120 μm in diameter) was run through a mail hole of a flat steel heald as a test piece, and the flat steel heald is abraded in contact with the thread under conditions such that the flat steel heald was rotated 10 hours at 800 rpm (a sliding speed of 0.1 m/second) while a tension of 50 g was applied to the thread. Thereafter, a depth of an abrasion at the contact surface was measured, and a weight loss of the mail part abraded in contact with the thread was also measured. Abrasion resistance of each test piece was evaluated from a value M (%) ($=D_iD_0X100$) which was calculated as a ratio of an abrasion depth D_i of each test piece to an abrasion depth D_0 of a stainless steel SUS420J2 as a reference. A value M of 50% or less is necessary in order to obtain excellent abrasion resistance two times higher than a conventional flat steel heald made of a stainless steel SUS420J2.

[0040] Test results are shown in Table 4.

[0041] Rusts were generated on a surface of a test piece of Comparative Example 8 whose Cr content was less than 8.0 wt.%, but generation of rusts was not observed on a surface of any test piece of the other Examples whose Cr content is 8.0 wt.% or more. It is recognized from these results that Cr content of 8.0 wt.% or more is necessary for insurance of corrosion resistance. The value M of any Examples 8 to 10, in which Ti and Nb carbide precipitates were distributed at a ratio of less than 0.1 wt.% in total, was not so much smaller compared with a conventional member (Example 11). On the other hand, any test piece of

Examples 1 to 7, in which a total amount of Ti and Nb carbide precipitates were distributed at a ratio of less than 0.1 wt.% or more, had the value M below 03%. Such lower value M means the lifetime of a flat steel heald made of the newly proposed steel is three times longer than a conventional flat steel heald.

[0042] The inventors graphically illustrated a value M in relation with a total amount of Ti and Nb carbide precipitates and confirmed the presence of the relationship therebetween as shown in Fig. 3. It is apparent from Fig. 3 that the value M is decreased as the total amount of Ti and Nb carbide precipitate increased, and that an abrupt decrease of the value M occurs when the total amount of carbide precipitates is 0.1 wt.% or more. The value M is decreased to 50% or less by adjusting the total amount of carbide precipitates to 0.1 wt.% or more. Such small value M means the lifetime of a flat steel heald made of the newly proposed steel is two times longer than a conventional flat steel heald.

TABLE 4:

[0043] AN AMOUNT OF CARBIDE PRECIPITATES, ABRASION RESISTANCE AND CORROSION RESISTANCE OF EACH FLAT STEEL HEALD

Example No.	an amount of carbide precipitates (wt.%)			abrasion resistance a value M (%)	corrosion resistance	Note
	TiC	NbC	in total			
1	0.13	0.10	0.23	29.5	no rust	Present Invention
2	0.26	0.10	0.36	23.2	no rust	
3	0.70	0.44	1.14	12.6	no rust	
4	1.41	0	1.41	13.1	no rust	
5	0	1.11	1.11	11.1	no rust	
6	0.81	0.80	1.61	9.2	no rust	
7	1.90	0.59	2.49	8.5	no rust	
8	0.01	0	0.01	99.1	generation of rust	Comparative Examples
9	0.04	0.02	0.06	89.2	no rust	
10	0.05	0.03	0.08	69.5	no rust	
11	0	0	0	100	no rust	SUS420J2

[0044] According to the present invention as above mentioned, the newly proposed steel is bestowed with excellent abrasion resistance fairly superior to a conventional

structured-hardened or work-hardened steel by distribution of Ti, Nb, Zr, V and/or W carbide precipitates at a ratio of 0.1 wt.% in total in a steel matrix. These carbides have nearly the same hardness as hard particles such as alumina and silicon carbides which causes abrasive abrasion. Due to such excellent abrasion resistance, a weaving machine member, a sewing needle, an agricultural machine member such as a mowing tooth or a cutter blade made of the steel of the present invention can be used over a long period. Especially, the steel, in which Ti and/or Nb carbide precipitates are distributed at a ratio of 0.1 wt.% or more in total, is suitable as a weaving machine member such as a flat steel heald, a dropper, a reed dent or a tunnel reed due to excellent abrasion resistance.